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Genetic (co)variances for calving difficulty score in composite and parental populations of beef cattle: I. Calving difficulty score, birth weight, weaning weight, and postweaning gain[1]

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ABSTRACT: Heritability of 2-yr-old heifer calving difficulty score was estimated in nine purebred and three composite populations with a total of 5,986 calving difficulty scores from 520 sires and 388 maternal grandsires. Estimates were 0.43 for direct (calf) genetic effects and 0.23 for maternal (heifer) genetic effects. The correlation between direct and maternal effects was –0.26. Direct effects were strongly positively correlated with birth weight and moderately correlated with 200-d weight and postweaning gain. Smaller negative correlations of maternal calving difficulty with direct effects of birth weight, weaning weight, and postweaning gain were estimated. Calving difficulty was scored from 1 to 7. Predicted heritabilities using seven optimal scores were similar to those using four scores. The predicted heritability using only two categories was reduced 23%. Phenotypic and direct genetic variance increased with increasing average population calving difficulty score. The estimated direct and maternal heritabilities for 2-yr-old calving difficulty score were larger than many literature estimates. These estimates suggested substantial variance for direct and maternal genetic effects. The direct effects of 2-yr-old calving difficulty score seemed to be much more closely tied to birth weight than were maternal effects.

Key Words: Dystocia, Birth Weight, Weaning Weight, Heritability, Genetic Correlation

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Introduction

Calving difficulty in first-calf heifers increases the likelihood for mortality of the heifer and(or) her calf, increases time to rebreeding, and increases labor and veterinary costs (Laster et al., 1973; Philipsson, 1976; Meijering, 1984). Predicted and actual results show that genetic selection can reduce the incidence and severity of calving difficulty (Meijering and Postma, 1985). Direct (calf) and maternal (dam) genotypes both contribute to calving difficulty. Apparent genetic and phenotypic variances depend on the incidence of assisted births and whether assisted births are further classified by degree of difficulty.

Calving difficulty has been shown to be correlated with birth and postnatal weights. Birth weight is an effective correlated trait that can be used to reduce calving difficulty. However, selection only for reduced calving difficulty or birth weight will lead to lighter postnatal weight. Schemes for simultaneously changing or limiting change in calving difficulty, birth weight, and postnatal weight have been proposed (Dickerson et al., 1974; MacNeil et al., 1998). Key genetic parameters needed for developing these schemes and for genetic evaluation are the correlations between direct and maternal calving difficulty and birth and postnatal weights.

Objectives of this research were to estimate heritabilities for direct and maternal calving difficulty score and the expected effects of alternative scoring systems on the estimates in 12 purebred and composite populations. Genetic correlations of direct and maternal calving difficulty score with birth weight, adjusted 200-d weight, and postweaning gain are estimated.

Materials and Methods

Animals. Animals and their pedigree information used in this study are identical to those reported by Bennett and Gregory (1996). These animals were from an experiment comparing parental populations with initial and advanced generations of composites (Gregory et al., 1991b) at the U.S. Meat Animal Research Center (**USMARC**). Details on formation, selection,

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Table 1. Description of calving difficulty scores

Score	Difficulty level
1	No assistance given
2	Little difficulty, assisted by hand
3	Little difficulty, assisted with calf jack
4	Slight difficulty, assisted with calf jack
5	Moderate difficulty, assisted with calf jack
6	Major difficulty, assisted with calf jack
7	Caesarean birth
8[a]	Malpresentation

[a]Scores of 8 were deleted from analyses by setting them to missing values.

and mating of these populations are available in the cited publications.

Data. Birth weight, 200-d adjusted weaning weights, and 168-d postweaning gain data are the same as those found in Bennett and Gregory (1996). In addition, a score for degree of calving difficulty was assigned depending on the amount of assistance given at parturition. The degree of calving difficulty score ranged from 1 to 7, as described in Table 1. Scores were assigned by field personnel instructed on the scoring system and score definitions. Scores were obtained for all births but only scores from calves born as singles to 2-yr-old heifers were analyzed. If malpresentation caused a calf to be assisted, calving difficulty score was ignored by setting the score to a missing value.

Fixed Effects Threshold Analysis. Data on the incidence of heifer calving difficulty scores by population and sex of calf were analyzed for the fixed effects of population and sex of calf assuming scores were an ordered categorical realization of an underlying normal liability distribution. The method of Gianola and Foulley (1983) was used to estimate fixed effects and thresholds only. Expected changes in variance with increasing average calving difficulty score were determined from the estimated thresholds. Estimates of the thresholds and mean liabilities for the populations were then used to determine optimal scores and expected reductions in heritability using the natural scores (Gianola and Norton, 1981).

REML Analysis. A derivative-free, multiple-trait REML program (Boldman et al., 1993) was used to estimate (co)variance components for each population. Fixed effects for birth weight, adjusted 200-d weaning weight, and 168-d postweaning gain are described in Bennett and Gregory (1996) and include year, sex, composite generation, and age of dam effects. A single fixed effect defined by sex, year, and generation (composites only) was fitted to heifer calving difficulty score.

Random effects fitted to calving difficulty score were additive direct genetic, additive maternal genetic, and residual variances. Random effects fitted to birth weight and adjusted 200-d weight were additive direct genetic, additive maternal genetic, maternal common environment due to having the same dam, and residual effects. Only additive direct genetic and residual effects were fitted to 168-d postweaning gain. All possible covariances among direct and maternal genetic effects were estimated except three: direct calving difficulty score × maternal birth weight, direct calving difficulty score × maternal 200-d weight, and maternal calving difficulty score × maternal 200-d weight. These three covariances were thought to be small and unimportant based on similar covariances with birth weight (Bennett and Gregory, 1996). The covariance between maternal common environment effects for birth and 200-d weight was estimated.

Each population was independently analyzed, resulting in 12 estimates for each (co)variance component. The derivative-free iterative search procedure was stopped when the variance of two times the log-likelihood in the Simplex was less than 1×10^{-10}. However, analyses were restarted several times before and after

Table 2. Number of 2-yr-old heifer calving difficulty scores, sires, and maternal grandsires and average scores for each population

	Number of observations and ancestors			
Population	Calving difficulty scores	Sires	Maternal grandsires	Deviation from avg score % of mean
Angus	573	51	47	–33.84
Braunvieh	414	37	31	31.97
Charolais	427	43	37	–11.09
Gelbvieh	402	27	21	8.17
Hereford	343	35	24	–2.33
Limousin	313	37	27	–19.14
Pinzgauer	322	18	14	26.37
Red Poll	412	36	26	–10.04
Simmental	450	46	37	3.97
MARC I	846	71	48	9.22
MARC II	760	65	39	2.57
MARC III	724	54	37	–5.83
Total	5,986	520	388	

Table 3. Incidence of heifer calving difficulty scores for each population and sex

Population and calf sex	Calving difficulty score							
	1	2	3	4	5	6	7	8
Angus								
Female	232	9	14	27	3	2	1	3
Male	161	5	34	64	12	4	5	5
Braunvieh								
Female	79	11	16	58	17	10	12	4
Male	32	3	20	58	30	6	62	6
Charolais								
Female	134	10	22	38	12	9	3	4
Male	89	2	18	56	11	8	15	11
Gelbvieh								
Female	107	9	23	26	8	4	10	1
Male	56	2	27	57	30	10	33	10
Hereford								
Female	93	11	12	24	4	5	6	8
Male	59	3	39	49	11	3	24	9
Limousin								
Female	109	6	9	22	9	6	0	7
Male	76	2	16	32	14	5	7	2
Pinzgauer								
Female	64	10	16	22	11	6	6	8
Male	38	1	21	42	24	10	51	4
Red Poll								
Female	120	8	31	36	11	5	3	6
Male	72	4	43	49	16	3	11	7
Simmental								
Female	125	7	21	28	13	4	2	5
Male	77	6	38	48	17	7	57	9
MARC I								
Female	198	14	41	86	41	19	13	12
Male	138	7	40	119	52	19	59	10
MARC II								
Female	206	13	34	52	27	9	9	5
Male	129	11	58	95	42	11	64	8
MARC III								
Female	210	16	44	44	14	2	9	20
Male	134	14	50	93	39	13	42	13
Total								
Female	1,677	124	283	463	170	81	74	86
Male	1,061	60	404	762	298	99	430	94
All	2,738	184	687	1,225	468	180	504	177

reaching the stopping rule to reduce the chance of stopping at a local maximum.

Analysis of (Co)variances. Bennett and Gregory (1996) found that some differences among (co)variances were associated with type of mating system and with the average weight and milk production of the population. Variance of an ordered categorized trait is expected to change with its mean (Gianola and Norton, 1981). A regression analysis was used to identify associations between these factors and the estimated (co)-variances.

The 12 estimates for each (co)variance component were regressed on mating system, average weight, average milk, and average calving difficulty. Weightings based on number of observations for each population and covariates for mating system, weight, and milk were those used in Bennett and Gregory (1996). An unadjusted average heifer calving difficulty score for each population was used as the covariate for calving difficulty score. Seven df were available to estimate the empirical residual variance and standard errors of the intercept and four regression coefficients.

Results and Discussion

Numbers of 2-yr-old heifer calving difficulty observations and numbers of sires and maternal grandsires are shown in Table 2. The total of 5,986 observations from 520 sires and 388 maternal grandsires compares with 22,775 birth weight, 20,691 200-d weight, and 18,788 postweaning gain records from 880 sires and 711 maternal grandsires (Bennett and Gregory, 1996).

Table 4. Estimates of thresholds and effects for sex of calf and population from an ordered categorical analysis of 2-yr-old heifer calving difficulty scores

Effect	Estimate	SE
Thresholds		
1	0.857	0.055
2	0.941	0.055
3	1.259	0.056
4	1.919	0.058
5	2.283	0.059
6	2.474	0.060
Sex of calf		
Female	0	
Male	0.651	0.029
Population		
Angus	0	
Braunvieh	1.171	0.075
Charolais	0.506	0.076
Gelbvieh	0.777	0.076
Hereford	0.602	0.080
Limousin	0.333	0.084
Pinzgauer	1.035	0.080
Red Poll	0.522	0.077
Simmental	0.697	0.074
MARC I	0.815	0.065
MARC II	0.684	0.066
MARC III	0.553	0.067

Unadjusted population average calving difficulty scores converted to percentage of differences from the overall mean calving difficulty score are shown in Table 2. These differences are subsequently used as covariates to analyze (co)variance estimates.

Incidences of calving difficulty score by breed and sex are shown in Table 3. Heifer calves were assisted in 43.3% of births and 66.9% of male calves were assisted. Approximately 3% of births were recorded as malpresentations and their calving difficulty scores were excluded from analyses.

Estimates of thresholds and liabilities for sex of calf and population are shown in Table 4. When liability differed by at least 0.2, estimates of breed effects ranked the same as estimated calving difficulty percentage from 2-yr-old dams analyzed as two categories by least squares (Gregory et al., 1991a). As expected, male calves were more liable to experience difficulty at birth; however, the range in liability of breeds was nearly twice the difference in male and female liability.

Expected mean calving difficulty score and variance of scores can readily be determined using estimated thresholds to find proportions. Figure 1 shows the relationship between expected mean calving difficulty score and phenotypic variance. Using the estimated liabilities for the 12 populations, the expected increase in phenotypic variance is 0.034 per percentage of deviation from the mean.

The method of Gianola and Norton (1981) was used to examine expected differences in heritability of underlying distribution and heritability calculated with optimal and suboptimal scores. The method was applied to predicted proportions for each of the 12 populations based on the estimated thresholds and population mean liabilities plus half the sex of calf difference from Table 4. Table 5 shows that heritabilities calculated with optimal scores were not much different from the natural scores of 1 to 7. The optimal score for the second category, assistance by hand with little difficulty, would have been greater than 2 in all populations. On average, optimal scores are expected to result in a heritability that is 0.814 of the underlying heritability. Heritability using seven consecutive integers was almost identical to heritability using optimal scores. This suggests that there is little to be gained by threshold analysis of these data for variance components as long as year effects are not large and calving difficulty scores from 2-yr-old heifer and older cows are not combined.

Scoring calving difficulty on a coarser scale using integers 1 to 4 results in a predicted average proportional decrease in heritability of 0.03. Using the still coarser scale of two integers, indicating assistance or no assistance, resulted in a predicted proportional decrease in heritability of 0.23. Expected heritabilities from populations with lower incidence of calving assistance, such as Angus, were less affected by number of classes, whereas expected heritability in higher-incidence breeds, such as Braunvieh, were affected much more by number of calving difficulty classes.

Estimated heritabilities of 2-yr-old calving difficulty from REML analyses are shown in Table 6. Average estimates of direct, offspring-dam, and total heritabilit-

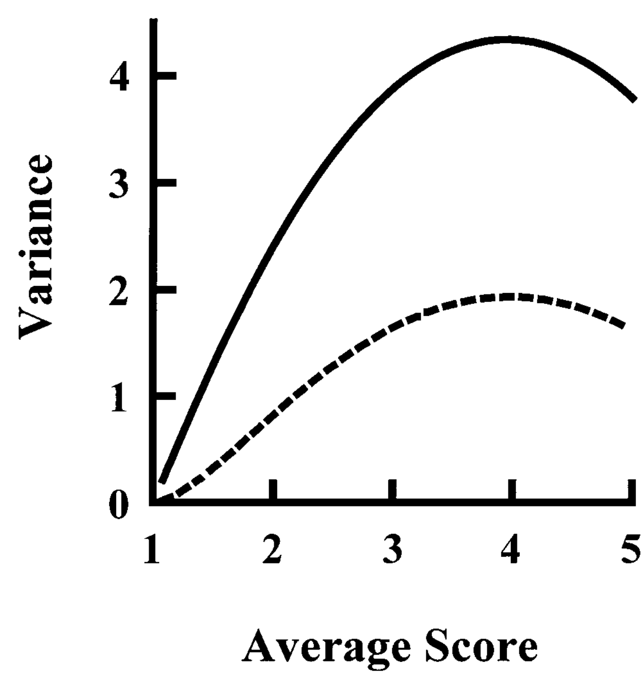

Figure 1. Predicted effect of average heifer calving difficulty score on phenotypic (solid line) and genetic variance (dashed line) assuming an underlying heritability of 0.5.

Table 5. Predicted ratios of heritability with optimal scoring (h_o^2) to underlying heritability (h^2) of calving difficulty score and predicted ratios of heritability (h_{subo}^2) of three suboptimal scoring systems to optimal scoring

Difficulty level	Assigned score			
	Optimal[a]	Natural	All or none	Four scores
None	1	1	1	1
Little, hand	2.41–3.13	2	2	2
Little, jack	2.86–3.52	3	2	2
Slight, jack	3.91–4.43	4	2	3
Moderate, jack	5.02–5.50	5	2	3
Major, jack	5.63–6.08	6	2	4
Caesarean	7	7	2	4
Population	$h_o^2:h^2$	$h_{subo}^2:h_o^2$		
Angus	0.646	0.982	0.889	0.972
Braunvieh	0.891	0.997	0.615	0.945
Average	0.814	0.993	0.760	0.964

[a]Optimal scores were calculated from Gianola and Norton (1981) and scaled from 1 to 7. Optimal scores depend on the mean liability for the population. The range of optimal scores for each difficulty level from the 12 populations are shown.

ies were near 0.4. Average maternal heritability was 0.22. Variability of estimates among the populations is expected to be partially due to the limited number of observations (Table 2) in each population. Negative sampling covariances between estimates of direct and maternal genetic variances result in variation among estimates that is partially averaged out in offspring-dam and total heritability estimates (Meyer, 1992). Using the ratios in Table 5 with the average heritabilities for direct and offspring-dam relationships suggests an underlying heritability of 0.5. Predicted genetic variance for calving difficulty score depending on the average score is shown in Figure 1 based on an underlying heritability of 0.5.

The relatively small sample sizes for 2-yr-old calving difficulty observations in each population limit the usefulness of individual population estimates. One way of combining estimates while retaining some degree of individual population variability is to regress estimates on potential explanatory variables that differ between populations. Estimated intercept and regression coefficients could then be used to estimate (co)variances for individual populations as well as identify causes of (co)-variance component differences. Regression analyses of (co)variance components involving calving difficulty score for differences attributable to mating system and percentage of differences between populations in average weight, milk production, and calving difficulty score are shown in Table 7.

Intercept values of (co)variance components were significant except for residual covariances between calving difficulty score and either 200-d weight or postweaning gain. Mating system did not significantly affect phenotypic or genetic variances for calving difficulty score.

Table 6. Heritability estimates for calving difficulty score

Population	Direct	Maternal	Offspring-dam[a]	Total[b]
Angus	0.29	0.14	0.36	0.43
Braunvieh	0.61	0.07	0.65	0.68
Charolais	0.26	0.25	0.50	0.70
Gelbvieh	0.32	0.40	0.35	0.44
Hereford	0.46	0.35	0.28	0.22
Limousin	0.12	0.25	0.20	0.29
Pinzgauer	0.72	0.05	0.75	0.77
Red Poll	0.27	0.27	0.40	0.54
Simmental	0.34	0.28	0.32	0.34
MARC I	0.50	0.17	0.50	0.52
MARC II	0.60	0.23	0.51	0.48
MARC III	0.28	0.27	0.17	0.13
Purebred avg	0.37	0.23	0.42	0.49
Composite avg	0.46	0.22	0.40	0.39
Overall avg	0.41	0.22	0.41	0.45

[a]Sum of direct genetic, 0.5× maternal genetic, and 1.5× direct-maternal genetic covariance divided by phenotypic variance.
[b]Sum of direct genetic, maternal genetic, and 2.5× direct-maternal genetic covariance divided by phenotypic variance.

Table 7. Regression coefficients for 2-yr-old calving difficulty score (co)variances on mating system, average weight, average milk yield, and average calving difficulty score (CDS)

(Co)variance	Intercept	Mating system	Avg[a] wt	Avg[b] milk	Avg[c] CDS	RSD
Calving difficulty score (CDS) genetic (co)variances						
Direct CDS	1.756 ± 0.165	0.221 ± 0.183	0.002 ± 0.048	–0.012 ± 0.018	0.052 ± 0.015	0.551
Maternal CDS	0.861 ± 0.133	0.016 ± 0.148	0.031 ± 0.039	–0.013 ± 0.015	0.001 ± 0.012	0.444
Direct × maternal	–0.361 ± 0.089	–0.204 ± 0.099	0.014 ± 0.026	0.010 ± 0.010	–0.011 ± 0.008	0.297
Covariances between direct genetic effects for CDS and direct effects for weights						
CDS × birth wt, kg	4.247 ± 0.281	1.020 ± 0.311	0.020 ± 0.082	–0.018 ± 0.031	0.074 ± 0.025	0.935
CDS × 200-d wt, kg	8.17 ± 0.74	4.64 ± 0.82	–0.33 ± 0.22	0.18 ± 0.08	0.04 ± 0.07	2.47
CDS × 168-d gain, kg	7.63 ± 1.36	4.20 ± 1.51	–0.08 ± 0.40	–0.05 ± 0.15	0.18 ± 0.12	4.53
Covariances between maternal genetic effects for CDS and direct effects for weights						
CDS × birth wt, kg	–0.727 ± 0.223	–0.470 ± 0.248	0.138 ± 0.065	–0.017 ± 0.025	–0.032 ± 0.020	0.746
CDS × 200-d wt, kg	–3.25 ± 1.05	–1.99 ± 1.16	0.63 ± 0.31	–0.14 ± 0.12	–0.12 ± 0.10	3.50
CDS × 168-d gain, kg	–3.90 ± 0.53	–2.83 ± 0.59	0.48 ± 0.16	0.00 ± 0.06	–0.17 ± 0.05	1.76
Covariance between maternal genetic effects for CDS and birth weight						
CDS × birth wt, kg	0.471 ± 0.122	–0.046 ± 0.135	0.059 ± 0.036	0.012 ± 0.013	–0.032 ± 0.011	0.405
Residual (co)variances						
CDS	1.647 ± 0.138	0.069 ± 0.153	0.010 ± 0.040	0.003 ± 0.015	–0.001 ± 0.012	0.460
CDS × birth wt, kg	1.674 ± 0.269	–0.210 ± 0.299	0.086 ± 0.079	–0.016 ± 0.030	0.001 ± 0.024	0.897
CDS × 200-d wt, kg	0.13 ± 0.92	–1.43 ± 1.02	0.19 ± 0.27	–0.16 ± 0.10	0.10 ± 0.08	3.07
CDS × 168-d gain, kg	0.63 ± 0.97	–0.05 ± 1.07	–0.17 ± 0.28	0.08 ± 0.11	0.00 ± 0.09	3.21
Phenotypic variance						
CDS	3.903 ± 0.054	0.102 ± 0.060	0.057 ± 0.016	–0.013 ± 0.006	0.038 ± 0.005	0.179

[a]Average percentage deviations of unadjusted birth weight, 200-d weight, and 168-d gain.
[b]Percentage differences in average estimated 200-d milk yield based on weight/suckle/weigh observations.
[c]Percentage deviation in average calving difficulty scores of 2-yr-old heifers.

Weight traits had larger positive covariances with direct calving difficulty score and larger negative covariances with maternal calving difficulty in composite populations than in purebred populations. Larger average population weight increased the phenotypic variance for calving difficulty and the covariances between maternal calving difficulty and direct effects for the weight traits. Average population differences in milk had little relationship to calving difficulty (co)variances.

Average population differences in calving difficulty score were positively associated with direct and phenotypic calving difficulty score variance. Increased average calving difficulty was also positively associated with the covariance between direct effects for calving difficulty and birth weight and negatively associated with covariance between maternal effects for calving difficulty score and birth weight. The negative covariance between maternal calving difficulty and direct postweaning gain decreased as the population mean for calving difficulty increased. Using the actual population means and the expected phenotypic and genetic variance (Figure 1), the expected change in phenotypic variance was 0.034 per percentage of change in average difficulty score, compared to the slightly higher estimated value of 0.038 ± 0.005. Change in genetic variance was expected to be 0.019 compared with the much higher, but nonsignificantly different, estimated value of 0.052 ± 0.015.

Table 8. Calving difficulty score direct and maternal heritabilities and genetic and environmental correlations with birth weight, 200-d weight, and 168-d postweaning gain

		Genetic correlations				
		Direct effects			Maternal effects	
Calving difficulty score effect	h^2	Birth wt	200-d wt	168-d gain	Calving difficulty	Birth wt
Direct	0.43	0.81	0.41	0.36	–0.26	
Maternal	0.23	–0.16	–0.20	–0.23		0.34

	Residual correlations		
	Birth wt	200-d wt	168-d gain
Residual	0.41	0.02	0.03

Table 8 shows heritabilities and correlations computed from weighted average (co)variances. Direct heritability exceeded maternal heritability and the correlation between direct and maternal was small and negative. Direct effects for calving difficulty score and birth weight were highly positively correlated. Maternal effects for calving difficulty score and birth weight were also positively correlated, but the correlation was less than half the direct correlation. Direct genetic effects for calving difficulty were moderately positively correlated with 200-d weight and 168-d gain. Maternal genetic effects for calving difficulty were negatively correlated with direct effects for birth weight, 200-d weight, and 168-d postweaning gain.

The negative correlation for direct and maternal genetic effects for calving difficulty score is slightly antagonistic to simultaneous improvement of both effects. The high correlation of direct additive genetic effects for birth weight and 2-yr-old calving difficulty score suggests limited potential for improving calving difficulty without also decreasing birth weight. The lower correlation of maternal genetic effects for calving difficulty and birth weight suggests that maternal calving difficulty could be improved with little change in maternal birth weight. However, variation in maternal genetic calving difficulty is less than direct effects and maternal genetic birth weight is less than 10% of total variation. Direct and maternal genetic variation in calving difficulty score that was independent of birth weight was 15% and 20% of total variance, respectively.

The pattern of correlations with 200-d weight and postweaning gain suggests that selection for postnatal weights will increase calving difficulty through direct effects and decrease calving difficulty through maternal effects. The net effect of selection for postnatal weights would be an increase in calving difficulty because the correlations with direct effects are stronger, the direct heritability is greater, and there is a generational lag in the expression of maternal effects. Moderate correlations between calving difficulty score and postnatal weights are antagonistic but low enough so that a genetic decrease in calving difficulty and increase in weight should be possible with a disciplined selection program.

Koots et al. (1994a) found estimates of about .1 for direct and maternal calving difficulty in a summary of heritability estimates. Their averages were less than those of the current study and direct estimates were not larger than maternal estimates of heritability. Reasons for these differences are not known but might be due to a relatively high incidence of assistance, the unselected populations, or the more complete accounting of natural selection and additive genetic relationships. Averages of limited numbers of correlation estimates (Koots et al., 1994b) were similar in direction to those of this study.

Implications

In purebred and composite populations of beef cattle, heritability of difficulty among calves born to 2-yr-old heifers was moderate, indicating genetic progress is possible if calving assistance observations are recorded and used in genetic evaluation systems. Using more than four calving difficulty scores or optimal (noninteger) scores was predicted to have little effect on the heritability of calving difficulty. Using only two scores, assisted or unassisted, would reduce heritability. Birth weight is strongly correlated with the effects of the calf on assistance rates. Progress in reducing calving difficulty will likely require reduced birth weights.

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